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Optimization of InGaAs/InGaAsP MQW Semiconductor Amplifiers

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Semiconductor optical amplifiers (SOAs) based on quantum-wells (QW) are reported to have a low noise figure [1] and a large gain bandwidth [2] compared to bulk SOAs. These features make the QW SOA an attractive component for use as a pre-amplifier in future OEICs. In this paper the optimization of QW-structures for a low noise figure and a high gain is considered. Contrary to previous work [3], our model suggests that the noise figure does not depend critically on the number of wells. In addition, the predictions are compared to measurements of the noise figure and gain for a multiple quantum-well (MQW) amplifier.

The gain is calculated using the **k·p**-approximation, taking into account both the conduction band/heavy hole band and the conduction band/ light hole band transitions. The noise figure is found from the formula [2],[4]:

$$F = 2\frac{\Gamma\alpha_e}{\Gamma g-\alpha_{loss}} \equiv 2\gamma_{sp}\frac{g}{(g-(\alpha_a-\alpha_b))-\alpha_b/\Gamma}$$

where Γ is the optical confinement factor, α_e is the rate of stimulated emission of photons into the optical mode divided by the group velocity of light, g the gain, $\gamma_{sp} \equiv \alpha_e/g$ defines the population inversion parameter, α_a is the loss in the active layers and α_b the loss in the barrier layers. Although small, the barrier loss has substantial effect on the noise figure, due to the little confinement factor. The increase in junction temperature due to the injection current has been included in the model.

In Fig.1 the gain and corresponding noise figure are shown for 500 and 800 µm long 4-well MQW amplifiers as a function of injected current with the well width as a parameter. The gain and the noise figure are optimized for a well width of approximately 40 Å as a result of several effects [3]. The increase of the confinement factor and the approach of the heavy-hole and light-hole confined states to each other act to increase the gain with the well width. On the other hand the increase in the density of states with well width lowers the Fermi-levels, thereby reducing the gain. Experimental results for the single-pass gain and noise figure at the gain peak (TE-polarization) are also shown in Fig. 1 for comparison. The agreement between the calculated and the experimental results is acceptable and taken as a verification of the model.

The above results show an optimum well width of 40 Å. In practice it is convenient to use InGaAs and InGaAsP lattice matched to InP. This implies a well width around 80 Å for a wavelength of 1.5 µm The model is therefore used to evaluate the noise figure dependence on the number of wells, N_Q, for this well width. From the equation it is clear that the noise figure is minimized when the confinement factor is large, as in the case of many wells. However, if the length, L, of the amplifier is kept constant the carrier density will drop due to the larger active volume. To analyze this, two cases are considered, namely 1) constant amplifier length and bias current as in [3] , and 2) constant active volume and gain. In the first case the noise figure increases with the number of wells, because the carrier density drops. This is shown in Fig. 2 (open circles) for an 800 µm long amplifier. The bias current is 150 mA. Despite the decreasing carrier density the gain increases with the number of wells as shown in Table 1. This is due to the increase in the confinement factor. Thus, a trade-off exists between noise figure and gain. In the second case the length is reduced as to keep the active volume constant. The bias current is adjusted to give a single-pass gain of 20 dB. As seen in Fig. 2 (closed triangles), the noise figure decreases slightly with the number of wells because while the carrier density remains constant, the influence of the barrier losses are minimized. The benefit of using many parallel wells is reduced by higher operating temperatures as seen in the table where a detailed list of parameters is given. As the dependence of the noise figure on the number of wells is negligible, the optimum well number is 4-6 considering realistic lengths and low operating temperatures.

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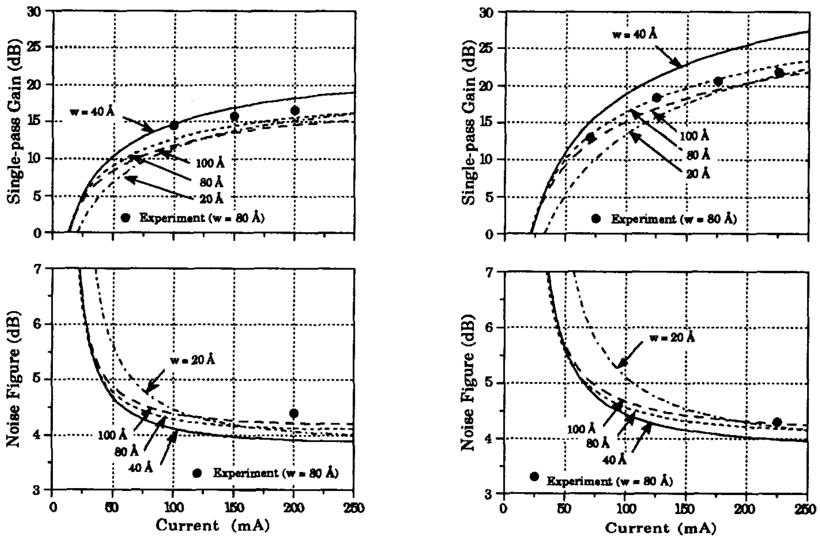

Fig. 1 Single-pass gain and noise figure vs. current density for 4-well amplifiers with the well width as parameter. The amplifier lengths L are 500 and 800 μm, respectively.

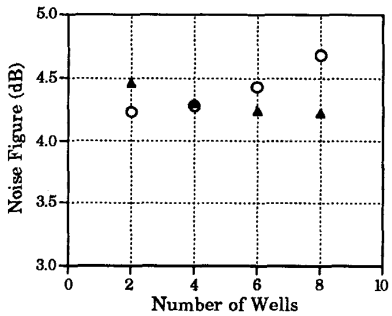

Fig. 2 Noise figure vs. number of wells. Open circles are for L = 800 μm, bias constant at 150 mA. Closed triangles are for G = 20 dB with length adjusted to give constant active volume. Well-width is 80 Å.

Table 1 Noise figure and parameters corresponding to the two cases considered in Fig. 2.

N_Q	L=800μm, Bias=150mA			Gain = 20 dB			
	NF dB	Gain dB	Temp K	NF dB	L μm	Bias mA	Temp K
2	4.23	12.6	293	4.46	1600	168	297
4	4.28	20.2	293	4.30	800	155	302
6	4.43	26.0	293	4.25	533	158	310
8	4.68	29.1	293	4.22	400	176	322